6.1 A WiMedia-Compliant UWB Transceiver in 65nm CMOS

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Ultra wideband (UWB) is an emerging broadband wireless technology enabling data rates up to 480Mb/s and beyond. Although the FCC opened up the spectrum for UWB operation in the 3.1-to-10.6GHz range, the WiMedia Alliance currently addresses the spectrum from 3168 to 4752MHz (Band Group 1) and 6336 to 7920MHz (Band Group 3) to allow worldwide operation using MB-OFDM UWB [1]. A low-noise highly linear receive chain is required to enable co-existence with systems operating in the 2.4 and 5GHz bands that produce strong out-of-band interferers. In this paper, a low-noise dual-band transceiver for UWB radio is described. The transceiver is realized in a 65nm CMOS technology and uses a 1.2V supply. A small active die area is obtained by using a minimal number of inductors.

Figure 6.1.1 shows the transceiver block diagram. The zero-IF receiver architecture consists of a wideband LNA capable of covering both band groups. Two voltage-to-current converters follow the LNA, each driving a passive mixer. A 1st-order filter section with a nominal bandwidth of 264MHz follows each mixer. The transmit chain uses a direct-upconversion technique consisting of a baseband (BB) filter section, passive mixers, and a power amplifier (PA). An integrated inductor acts as matching network and connects both LNA and PA to the same RF pin, which has a dedicated low-capacitance layout and diode-based ESD protection. The inductor connects the RF pin to the gate of the LNA and has a tap to connect the PA. The LO signals are provided by three integrated RC ring oscillators. This set-up together with a multiplexer circuit allows performing fast frequency hopping, as has also been demonstrated in [2]. The PLL needed to lock the oscillators is not yet included, but there are no stringent requirements to its design. As an alternative, an external LO signal can be applied to the UWB transceiver test chip. Balanced quadrature signals are generated on-chip, by a dedicated single-ended-to-differential buffer and a high-speed frequency divide-by-2 circuit operating up to 20 GHz. An integrated multiplexer allows to select between the LO signals and is followed by a dedicated LO buffer to drive both receive and transmit mixers. Additional units on the chip are a biasing block and some control logic.

The LNA is based on a cascode configuration with inductive feedback to the source. The LNA has a single-ended RF input. Passive phase splitting by means of an integrated transformer is applied to transform the single-ended output into a differential signal. In this way, an external wideband balun at the input, which would add undesirable loss and cost, can be avoided. The same transformer is used to provide the voltage feedback to the source, similar to what has been described in [3]. Double loop matching is obtained by a current feedback loop using a resistor between the output and the input. Current draw of the LNA is 15mA. The transformer-based LNA is described in more detail in [7].

The RX BB filter is implemented using a transimpedance amplifier (TIA), as in a passive mixer the signal is in the current domain and a virtual ground node is required. Optimal gain partitioning between LNA and TIA together with the use of a passive mixer leads to a highly linear receive chain. The TIA has a low noise figure (4dB simulated). It includes an opamp and a bridged-T RC feedback structure to realize the complex conjugate pole pair [4]. The 3-stage opamp schematic is shown in Fig. 6.1.2. The input NMOS transistors are biased in weak inversion to get better current efficiency for improved noise performance at low power levels. The output stage is a class-A push-pull configuration, doubling the current drive of the opamp. The Rc and Cc components are used for differential mode frequency compensation. The opamp has a unity-gain bandwidth close to 4GHz and draws 10mA. The measured –3dB bandwidth of the filter is around 300MHz.

The RC-ring-oscillator topology contains four differential amplifiers in cascade, each providing 45° of phase shift at the oscillation frequency, and an extra 180° of phase shift in the crossed feedback path. Each VCO draws about 8mA for the highest frequency and has a measured phase noise below –88dBc/Hz at 1MHz offset.

On-wafer measurements are done on the behavior of the separate blocks as well as on the whole transceiver. In these measurements the PA (the final push-pull class A stage) in the TX path, could not be activated and instead the signal is measured at point X in Fig 6.1.1. The measured output spectrum, while transmitting QPSK-OFDM bursts, is shown in Fig. 6.1.3. The gain flatness in Band Group 1 is within 1dB, in Band Group 3 is within 2dB, and over the two band groups is less than 3dB. The transmitted output power is close to the required –42dBm/MHz, indicating that the requirements on the RF power amplifier are relaxed. The figure also shows the carrier LO feedthrough of subband 1 in Band Group 1, which measures less than –70dBm. Looking at other spurious tones, we see the second order harmonics of Band Group 1, which fall at subband edges of the higher band groups. These spurious tones are –13dB below the transmit mask while their position precisely falls between two adjacent subbands and therefore allow for co-existence with other UWB systems. The measured constellation diagram, while transmitting in subband 2, is shown in Fig. 6.1.4, indicating an EVM below 4%. Although this does not yet include the PA distortion, it is well below the required 8% and indicates a linear transmitter.

Figure 6.1.5 shows the measured performance of the complete receive chain. The NF is 5dB for subband 1 (Band Group 1) and 5.5dB for subband 9 (Band Group 3), showing a relatively flat noise figure over a wide bandwidth. The total power gain is 18dB (actual voltage gain is 24 dB) and shows less than 2dB drop over the entire frequency band. The figure also shows the input impedance matching (S_{11}). Since the package is an integral part of the matching strategy, on-wafer measurements of S_{11} only partly demonstrate the wideband matching behavior.

The transceiver is integrated in a baseline 65nm CMOS technology. Figure 6.1.7 summarizes the measured performance. A chip micrograph is shown in Fig. 6.1.6. The active area of the transceiver is less than 0.4mm^2. Although the supply voltage is limited, a highly linear receive chain has been realized. An out-of-band two-tone linearity test with tones at 5.2GHz and 5.8GHz (IEEE802.15) has an IIP3 of +5dBm. This means, for instance, that for two interferers of strength –20dBm each, the intermodulation product would only be –70dBm (input referred), which is almost at sensitivity level for an UWB system. Similarly, a 2.4GHz ISM tone together with a 5.2GHz tone show an IIP2 of +24dBm. The total current draw of the RX signal chain is 43mA, and for the TX chain is 38mA, while the LO generation draws 52mA (excluding the PLL), all from a 1.2V supply. In general the obtained transceiver performance compares favorably with other reported UWB CMOS transceivers [2, 5, 6].

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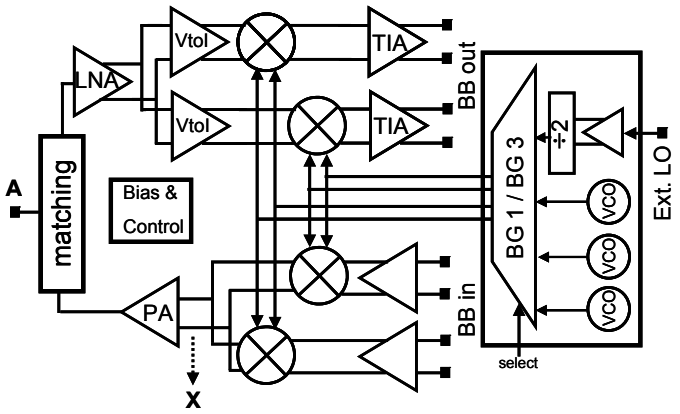


Figure 6.1.1: Block diagram of the UWB transceiver chain.

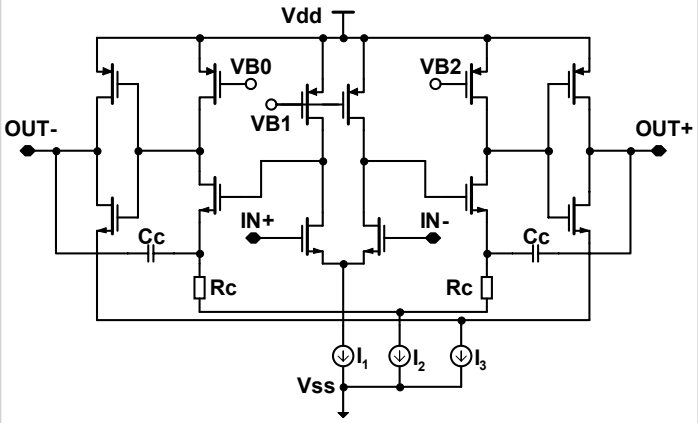


Figure 6.1.2: Circuit diagram of the opamp(biasing circuitry not shown).

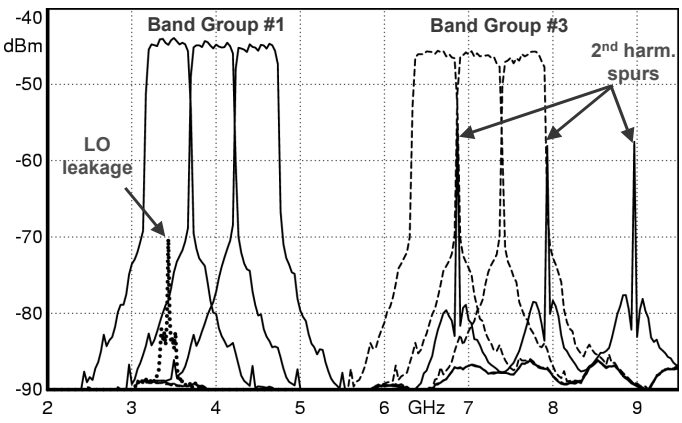


Figure 6.1.3: Transmit output spectrum including LO leakage and harmonic spurious tones, measured with RBW=1MHz at point X in Fig. 6.6.1.

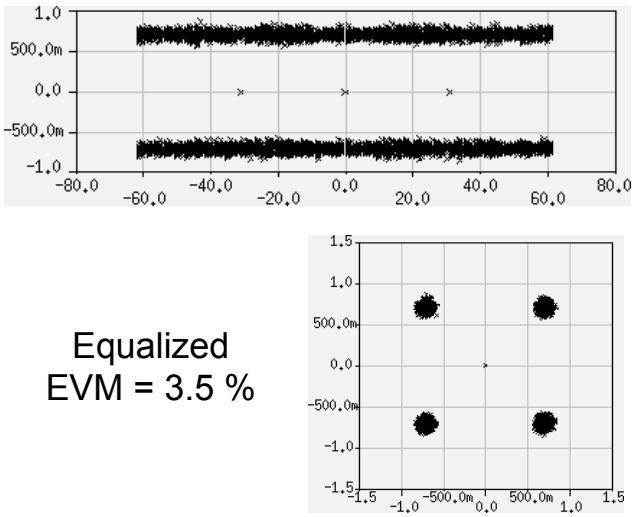


Figure 6.1.4: Measured QPSK output versus sub-carrier index, constellation diagram, and resulting EVM.

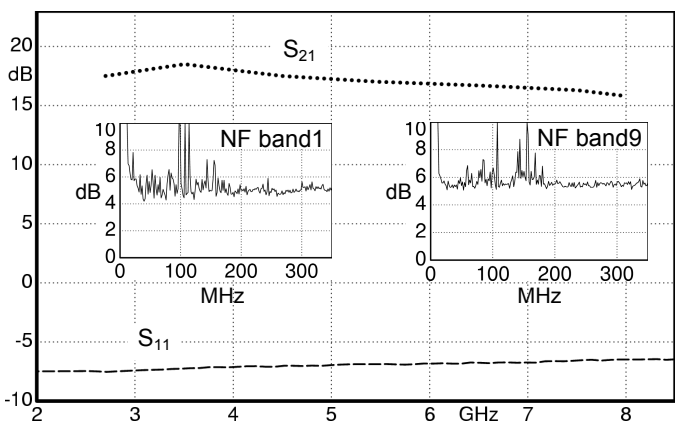


Figure 6.1.5: Measured receiver frequency response. Shown are power gain (S_{21}), return loss (S_{11}), and NF.

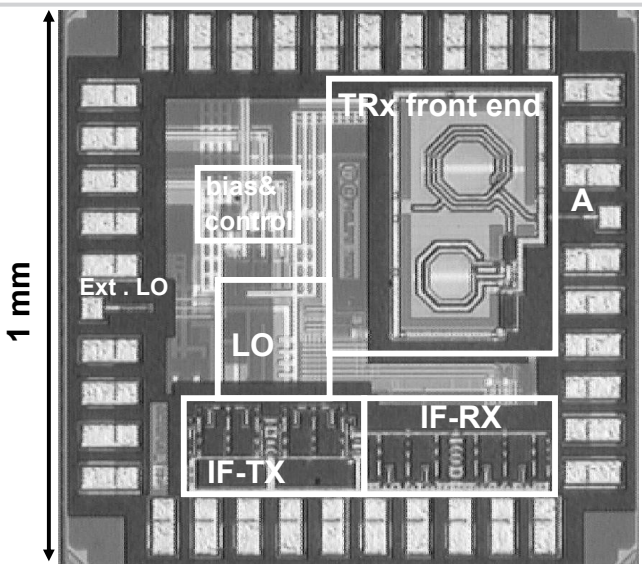


Figure 6.1.6: Die micrograph.

Continued on Page 590

Parameter	This work	Ref [2]	Ref [5]	Ref [6]
Technology	65nm CMOS	0.13µm CMOS	0.13µm CMOS	90nm CMOS
Band Group	1, 3	1	1	1, 3, 4
NF (dB)	5	6 to 7	4.1	6.9
IIP3 / IIP2 (dBm)	+5 / +24	-15	-22	-16
TX EVM (dB)	-28 (*)	-19.5	-27	-28
P_{diss} RX (mW) P_{diss} TX (mW)	114@1.2V 108@1.2V	100mA @ 3.3/1.5V 70mA @ 3.3/1.5V	237@1.5V 284@1.5V	224@1.1V 131@1.1V
Chip area (mm^2)	1	2	6.6	3.5

Figure 6.1.7: Measured properties of complete transceiver and comparison. NB: TX EVM in this work is measured without PA contribution, while in the TX power consumption the PA is included.

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